Advanced modelling of an electric vehicle module in the H2RES energy planning software

Goran Gašparović*
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Zagreb, Croatia
goran.gasparovic@fsb.hr
Goran Krajačić, Anamarija Šare, Neven Duić

ABSTRACT

The energy planning model H2RES [1] has been used successfully for planning of island and micro grid operations [2], [3], [4], [5], [6]. H2RES has been rewritten with new programming tools, revising the user experience in terms of usability and modelling abilities, while adding new optimization capabilities. Implementation of an Electric Vehicle (EV) module is the next step in the electrification of energy systems [7]. The methodology used to develop the EV module leans on the tested RenewIslands methodology [8] used for island and micro grid energy scenarios . The new version of H2RES solves the problems of the integration of energy systems with a high share of renewable energy sources (RES), and a transport system based on EVs [9]. Since EVs are currently in development, and limited commercial use, there is still insufficient data regarding their use [10]. Therefore, simulations are used to estimate the integration of EVs into energy systems. It is crucial to carefully plan the penetration of new technologies in both transport and energy systems and to determine how the new technologies interact [11]. The aim is to use the developed models to optimize EV penetration in energy scenarios such as a micro grid, consisting of a single vehicle and neighbourhood, to a whole fleet and entire regions. Additional goal is to improve on optimization results of H2RES compared to software packages that use an aggregated battery model for all the vehicles in an energy scenario.

The concept for the analysis of EV and RES integration includes a model of EVs in H2RES for the hourly balancing of energy systems. The main addition to H2RES model is the ability to integrate EVs into the energy planning by taking account of the energy price, State of Charge (SoC) of the battery and overall load on the energy system, thereby enabling RES to compensate for the increased demand in the grid. H2RES is able to model EVs in three modes: Dump Charge (DC), Smart Charge (SC) and Vehicle to Grid (V2G). Each mode poses a different set of rules and constraints on the energy system. The batteries are modelled as a single unit where they represent a group of EVs considered in the scenario. For test purposes, a simple case study of the island of Mljet and DC mode was calculated with 7 EVs and generic driving cycles with daily demand of 63 kWh. Yearly electrical demand for scenario was increased by 8%. All of the mentioned improvements and features were tested in a case study for the Dubrovnik region and compared to results obtained in similar energy planning tools. The results of the case study are presented in this paper.

Keywords:
Energy Planning, H2RES, optimization, EV, V2G

* Corresponding author

INTRODUCTION

The paper deals with Dubrovnik and its region, the Dubrovnik-Neretva County [**Figure 1**]. From the 2011 census, the basic statistics of the county are: area of 1781 km^2, 122870 inhabitants (2.8% of Croatia's total population), and 69 inhabitants per km^2, 5 cities, 17 municipalities and 230 settlements. All but one of the cities is located in the continental part of the County, and the County includes 6 major inhabited islands, and 1 large peninsula. With the population on the islands reaching a combined total of approximately 19000 inhabitants, the continental population is approximately 104000 permanent inhabitants. One national park is located on the island of Mljet. Main economic activities primarily stem from tourism, shipping industry, and to a minor extent, sea salt evaporation, agriculture, viticulture, olives and finally shipbuilding and masonry [12].

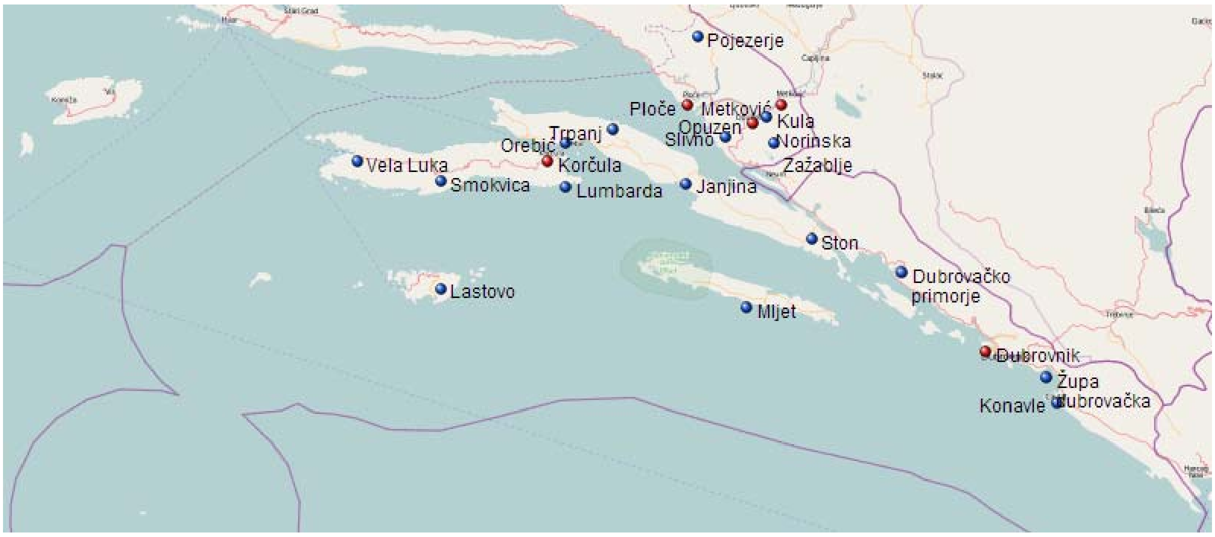

Figure 1. Overview of Dubrovnik-Neretva County

From the energy perspective, the County is connected to Croatian national grid by 110 kV connections over the islands and by one 220 kV connection via the neighbouring Bosnia and Herzegovina (BiH) [13]. Local energy generation capabilities include 1 hydro power plant, HE Dubrovnik, with the installed power of 2x108 MW, of which one generator provides electricity for the Croatian grid, and the other for BiH grid. Other installations currently (2013-08) include plans for 8 wind power parks for total installation of 491 MW (34 MW in test operation), 2 small hydro power plants of total 6.72 MW, and 4 small solar power plants of total 1 MW, none currently in operation [14].

The referent year used for the scenario was obtained from the transformer substation TS Komolac for the year 2010 [15]. This substation provides power for the majority of the population in the County, and therefore is considered representative for the modelling, given actual data was obtained on a 15-minute basis for that substation for the entire year. Note that the substation had a scheduled downtime for maintenance 2010, and the data was interpolated for the given period of 5 days (120h) in late September.

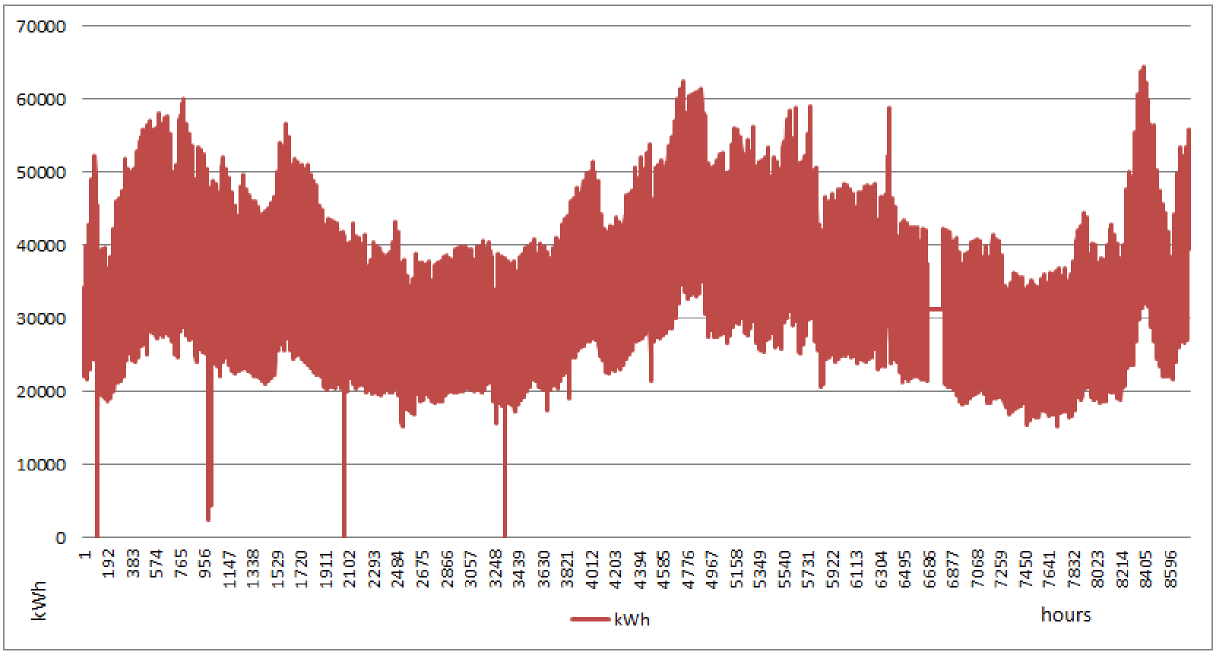

Figure 2. Yearly electricity demand for Dubrovnik region (2010.)

The data about electricity [Figure 2] consumption revealed a maximum load of 64.4 MWh, and an average load of 35.5 MWh. The peak periods occur during the summer months (tourist inflow and air conditioning use), and the winter months (heating implemented mostly with electricity, either thermal accumulation or air conditioning). Annual consumption was calculated at 310.65 GWh, compared to the national electricity consumption of 4763.8 GWh in 2010 [16], which amounts to 6.52% of total consumption. Since the region only comprises 2.89% of total national population, the difference could be explained by near complete reliance of heating/cooling demand on electricity and seasonal increase of population.

The wind and solar resources were mapped based on data from DHMZ [17]. Results were verified with HOMER Energy Modelling Software for wind data and PV-GIS for solar data and showed good correlation. The respective wind speed and solar irradiation curves are displayed here in [Figure 3] and [Figure 4]:

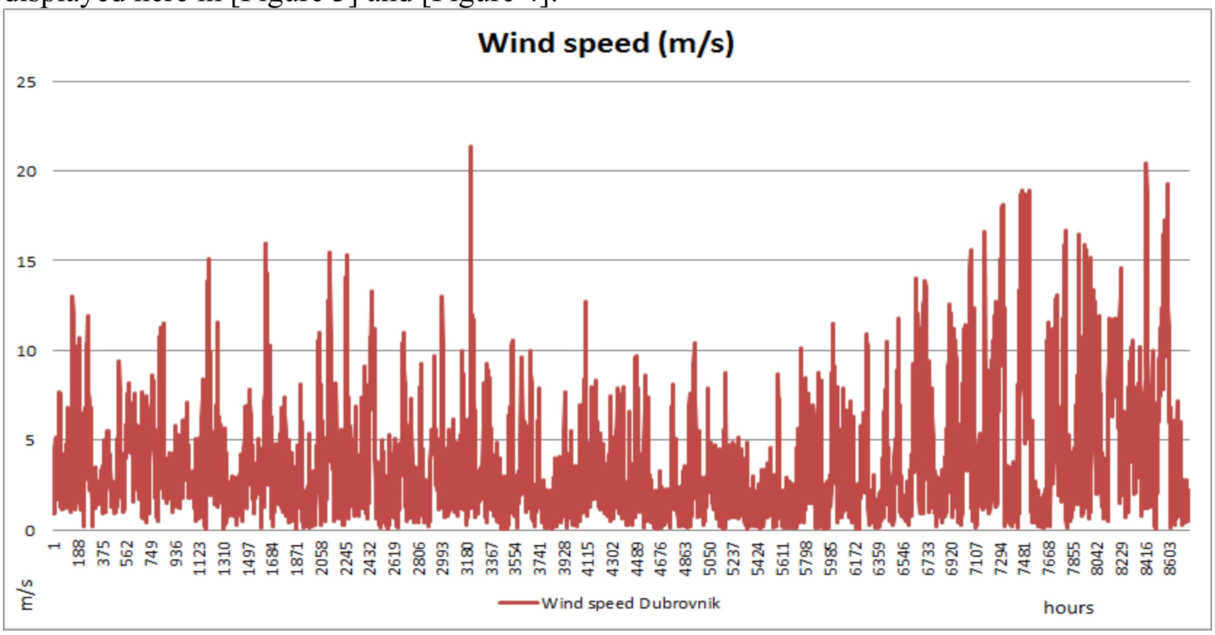

Figure 3. Yearly wind speed measurements for Dubrovnik

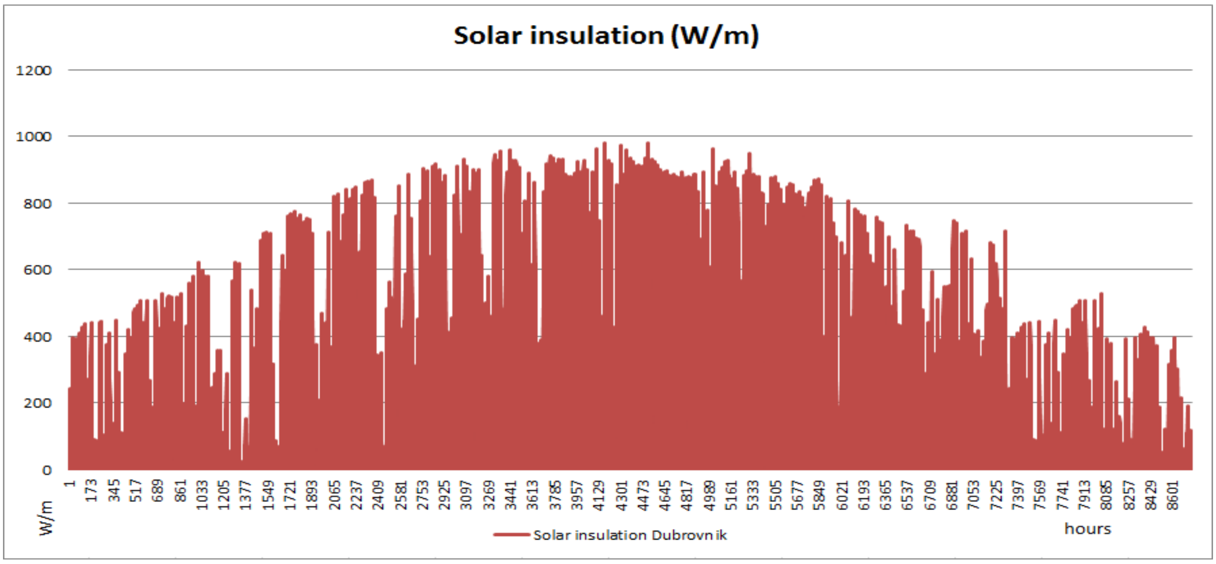

Figure 4. Yearly solar insulation measurements for Dubrovnik

Renewable Energy Sources (RES) are not installed in Dubrovnik area as of 2013, so the planned installations were increased over each time period of the energy scenario to reflect the higher penetration of intermittent sources. Given the amount of planned installations in the national Registry of RES [14], it was estimated that approximately 65% of wind installations would be developed by 2050, 33% by 2030 and 6.5% by 2020 [Table 1]. For solar power installations, only PV was considered at a rate of 100% in 2050, 50% in 2030, and 25% in 2020. Compared to earlier work [18], the Registry shows approximately 100 MW less of installed power in plans, but the installed capacity was kept the same, for ease of comparison and the fact the installations are already ahead of planned installed capacity, with wind power targets already being achieved in 2013 for the year 2020.

Table 1. Planned installations of RES in MW

Base year / Scenario year	2010.	2020.	2030.	2050.
Wind power (in MW installed)	0	32	160	320
Solar power (in MW installed)	0	9	18	36

Additionally, to model the increase in population and rise in electricity demand, for the years 2020, 2030 and 2050, the demand was manually increased compared to the base year of 2010 in order of 11.41%, 17.79% and 16.33%, respectively. This amounts to total increase of 52.4% over the period of this energy scenario.

The paper shows the integration of EVs is possible given the current state of electrical grid and available electricity generation capacities in the region. Also, given the amount of planned renewable energy sources (RES), there should be adequate available electricity to provide even for the increased base load and overall increase in EV consumption in 2050.
It also validated the H2RES model and showed that it significantly reduced time in setting up and calculating the same scenario compared to other similar energy planning tools [19].

METHODOLOGY

Regarding EVs, the current situation does not provide for any charging stations, nor are there any registered EVs in the County or Croatia [20]. The total number of registered vehicles in

2011 was 59674, 3.03% of the total national number of registered vehicles, 1969405 [20]. Of that number, on the area of interest (the city of Dubrovnik and the surrounding area in the radius of 15 km from the city centre) there were 22927 vehicles in 2010 and 16617 (1.36% of national number) personal vehicles. For determining the driving cycle of an average EV, a traffic study conducted by the city of Dubrovnik [21] was used, which sets the average daily commute distance at 45 km [Figure 5].

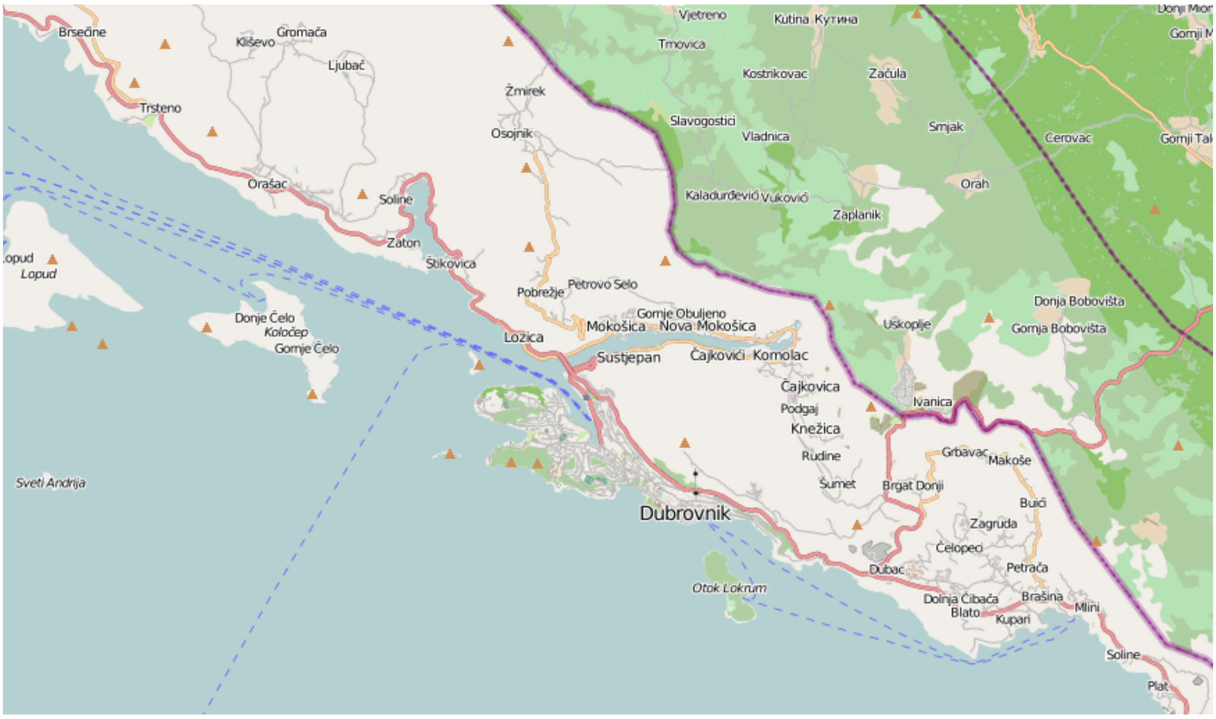

Figure 5. Considered area for integration of EVs

EV penetration was modelled on the following principles, taken over from the diploma thesis [18]. The level of penetration was adopted from the national study for Croatia [22], and gave the following numbers for each class of EVs. There were 3 classes of EVs under consideration, each comprising approximately the equal number of vehicle units.

Table 2. EV class characteristics

EV category	Battery capacity (kWh)	Radius (km)	Consumption (kWh/100km)	Network charge power (kW)
Small	10	100	10	2.2
Medium	20	130	15.38	4.4
Large	35	180	19.44	7.8

Following the traffic study [21] and the national study [22], these were the numbers of EV planned to enter the scenario at given scenario years [Table 2]. The national study suggests an increase in number of overall registered vehicles in Croatia, so the final number reflects the fact there are more EVs in the scenario in 2050 than vehicles overall in 2010, but keeps the ratio of vehicles in Croatia vs. Dubrovnik at 1.36% [Table 3].

Table 3. Number of registered EV personal vehicles, current and planned

Scenario year	2010	2020	2030	2050

EVs in CRO	0	10723	581802	1368462
EVs in DUB	0	146	7922	18635

H2RES MODEL, EV MODULE AND OPTIMIZATION DESCRIPTION

Detailed description of H2RES energy planning software lists all possible EV module modes and describes the functioning of EV module within the H2RES model, as well as the model itself.

Firstly, the H2RES model comprises of a *Scenario* (SC) [Figure 6], which is divided into yearly *Energy Systems* (ES), in which individual *Energy Sources* (SRC) and *Energy Buses* (EB) or vectors are defined. Each EB contains one or several *Bus Techs* (BT), a connection point for *Bus Nodes* (BN), onto which actual physical *Devices* (DEV) form connections to the grid.

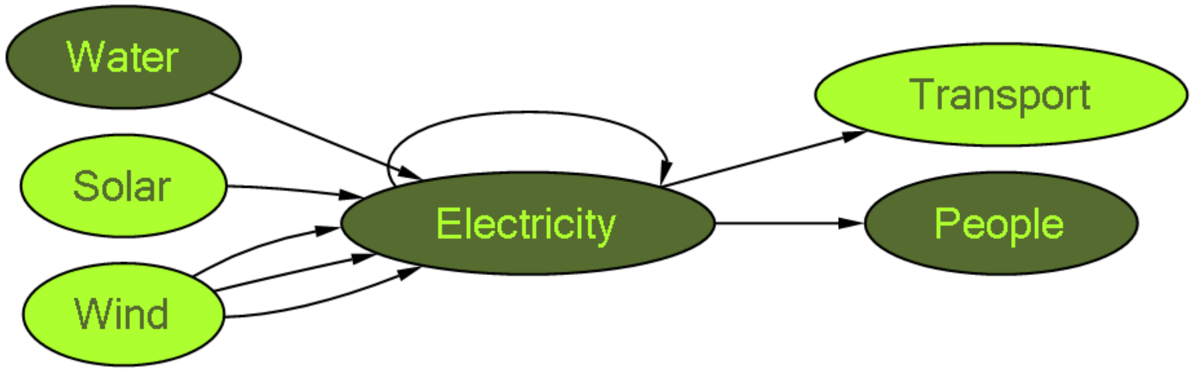

Figure 6. Layout of H2RES Scenario for Dubrovnik

Provisions were placed to input the descriptive parameters for each SC, ES and EB in the logical layout. Also, each EB defines prices for SRC, *Intermittent Limit* (IL) for the maximum allowable input of RES during 1h and the entire year, *Peak Load Week Limit* (PLWL), for defining the period during which storage discharge is allowed. Further, BN's define the total DEV count and *Discount Rate* (DR) for each BN, their location, and yearly inputs for *Transformations* (TR). On the DEV level, it is possible to input the *Investment Cost* (IC), *Lifetime* (LT), and define *Operations and Maintenance* (OandM) costs in three ways, as a percentage of IC, fixed amount per each DEV, or as an amount per kWh produced. Finally, each *Generating Device* (GENDEV) contains a *Power Curve* (PC), Minimum and Maximum Load and several descriptive fields for further defining the GENDEV in details. Additionally, *Storage Devices* (STODEV) have additional fields for describing the charge and discharge efficiency, maximum and minimum capacity, and number of charge and discharge cycles, along with all the previously mentioned parameters for DEV and GENDEV. Last logical division in the input section of H2RES refers to the demand side of the SC. H2RES deals primarily with the generation side of an energy scenario, and needs prepared inputs to be able to calculate properly. It operates by inputting 8760 point series, representing 1 year of data in hourly values.

H2RES emphasises use of RES in the calculations, therefore the order in which it engages the GENDEV depends on the type of GENDEV and its efficiency factor. Primarily, it uses RES until the quota of IL is met for that hour for each EB, and the order in which it uses these sources depends which intermittent source is the most efficient. From there it continues to the next most efficient, and so on. Depending whether the IL is reached for that hour or the entire potential of RES is used up, it switches to non-intermittent sources in the same order of

efficiency until the demand is satisfied. Finally, if there is still unmet demand, it will use the STODEV to ensure there is no Loss of Load Probability (LOLP) in a given hour. Extra step is taken into account for an open system with grid connection available. For that case, importing the electricity covers the difference in unmet demand.
EV module within H2RES model was created in a way to make use of two existing approaches [23] into energy planning. It may be implemented as an aggregate battery in which all the EV batteries are considered as single battery storage or it may be on an EV-by-EV basis. Naturally, it does not make sense to model each specific EV, but it opens a possibility to model classes of EVs in an energy scenario. As stated previously, there are 3 classes of EVs considered in the Dubrovnik scenario. Each one was modelled separately, since they all have different consumption demands, and in future, potentially different driving cycles.

Considering the modes of charging the EVs, H2RES supports two types of charge, and a hybrid charge/discharge mode to the electric grid.

- DC takes into account whether the vehicle is connected to the grid and proceeds to charge the EV regardless of the time of day.
- SC considers the price of electricity at a given period, and the driving cycle to delay the charging time until a more favourable window for charging is available. Those periods are generally at night when the demand and prices are lower.
- V2G is a hybrid mode that enables a vehicle to discharge its battery storage back into the grid at times of high demand. For that, all the constraints for the driving cycle need to be satisfied.

DC mode is easily implemented, with the only parameters needed for monitoring being the number of EVs connected to the grid. SC and V2G require more parameters, primarily energy prices for the hour. Other major parameters for SC include a pre-determined knowledge of driving cycles, which was provided manually as part of H2RES input. Without this information, SC might leave the EV without enough charge to complete its next journey. For V2G, along with all the other parameters for previous modes, it is necessary to know whether the parking place provides means to discharge battery capacity to the grid. Since all V2G projects are still in development phase, ratio of available EVs for V2G mode was left to be determined manually in the software.

After all the necessary data is gathered, it is the place of the optimization algorithm to provide the best possible solution.

EV INTEGRATION PROBLEMS AND SOLUTIONS

Major obstacles are present in the research of EV integration into existing electrical grid [24]. Most obvious aspect is the increase of electrical demand in general. Attention should be taken to address issues of transmission and distribution, and whether it is possible to deliver the amounts of electricity needed with the existing system. Those are mostly visible when dealing with quick-charge stations that require from 240 V/ 75 A to 500 V DC/ 125 A grid connections [25]. Some others include increasing the demand at unfavourable times if proper load balancing is not implemented. This leads to increasing the peak load and has a deterring effect of requiring more generating capacity to satisfy peak load demands. Proper distribution of charging stations needs to be taken into account when planning for EVs and costs included. Some countries implemented tax incentives and rebates to help introduce EVs more quickly into the fleet mix [26]. All the mentioned problems can lead to substantial additional costs and make EV integration a costly endeavour if not properly planned.

H2RES deals with the problem by making use of existing and future planned installations of RES, and by implementing SC and V2G modes into the EV module. Combined, the two approaches make the best use of RES and increase their penetration in the grid, while minimizing Critical Excess of Electricity Production (CEEP).

RESULT INTERPRETATION

The data required for modelling the EV fleet in this scenario was constructed outside of H2RES framework. It consists of defining an electricity demand per km of travel for all the EV groups in a scenario, and coupled with the pre-determined driving cycle gives an hour-by-hour electricity demand required for charging the EVs. This demand curve was the input for load parameter in the H2RES [Figure 7].

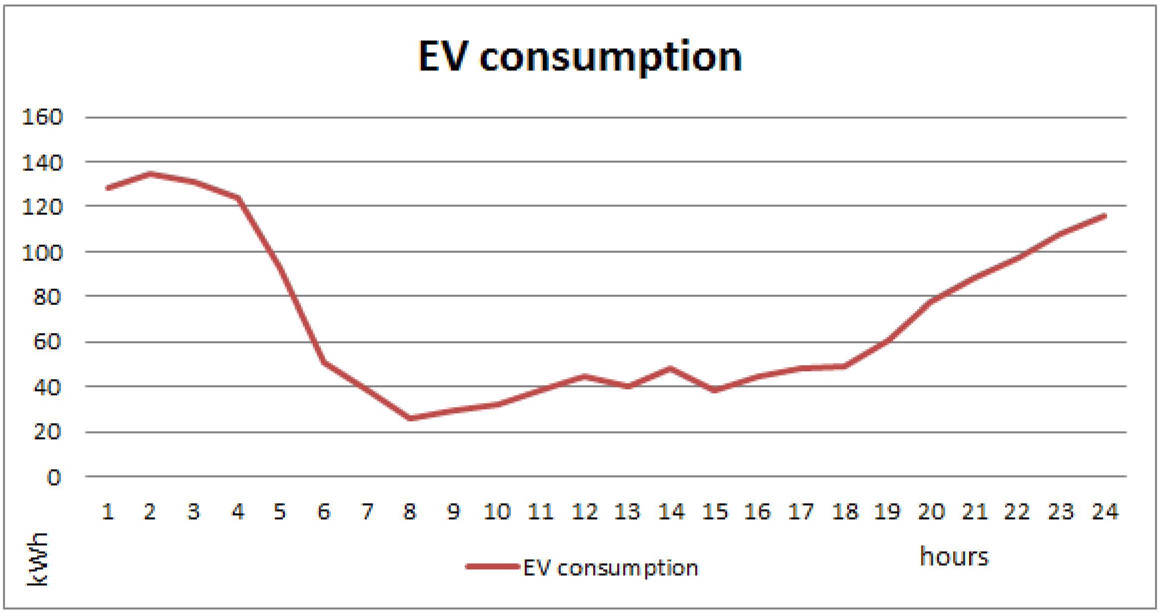

Figure 7. Daily aggregated consumption of electricity for an EV driving cycle

Since the driving cycles are the same for each EV group (small, medium, large), an aggregated curve combining all groups was used for calculating. Theoretically, different EV groups may have different driving cycles, and this was used in the beginning to verify the code. This ability of H2RES may be used further when new data becomes available in the future.

Consumption of EVs is displayed in [Figure 8], based on the number of EVs per class, its daily commute pattern of 45 km and multiplied by the average amount of electricity consumed per kilometre.

The overall storage capacities for the scenario are derived solely from the EVs, and are determined by the number of EVs in each scenario year, and the battery capacity for each class of EVs [Table 4].

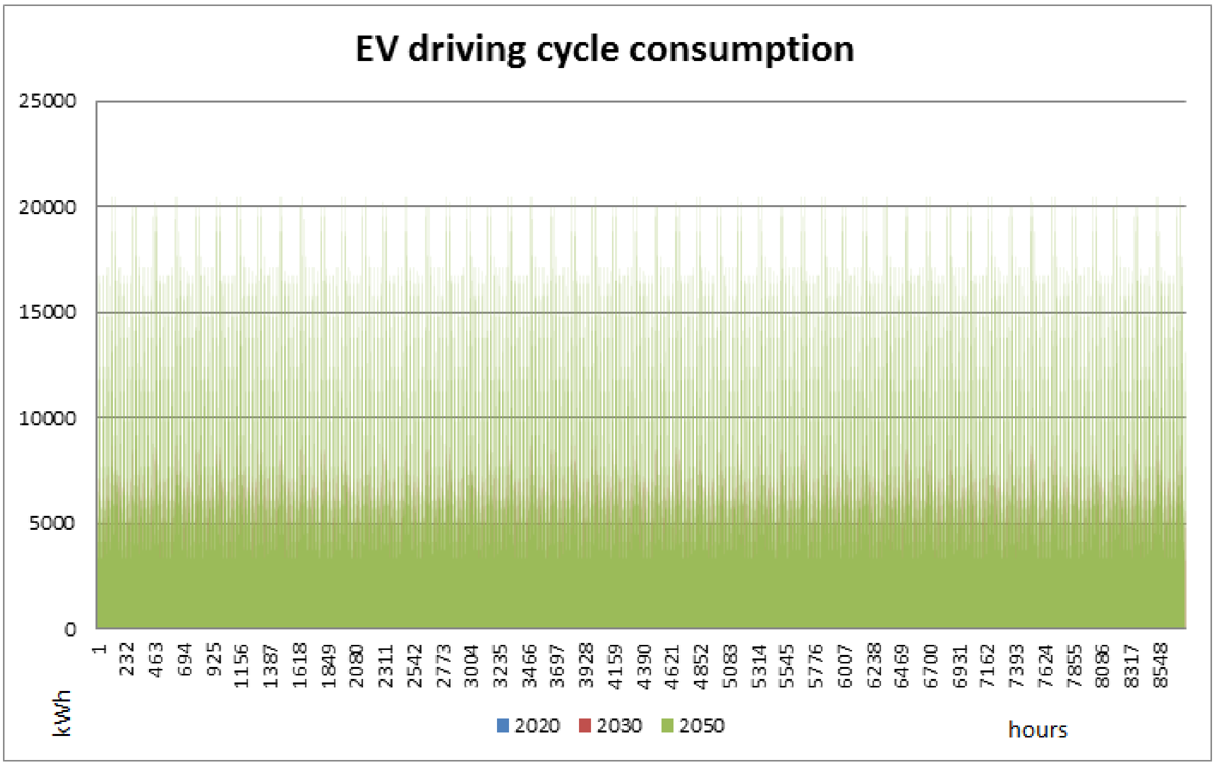

Figure 8. Total yearly consumption for EV charging in kWh

Table 4. Storage capacity of EVs in Dubrovnik

EV category	EV battery capacity (kWh)	2010	2020	2030	2050
Small	10	0	49	2641	6212
Medium	20	0	49	2641	6212
Large	35	0	48	2642	6211
Total capacity (kWh)		0	3150	171630	403745
Average available capacity (kWh)		0	2362,5	128722,5	302808,75

Due to the daily use of any vehicle, not all of the battery capacity is available at all times during the day. A relative scale was taken into account, and the peak time of day for EV use (approximately 08:00 in Figure 7) corresponds to 10% of EVs on the road. That leaves 90% of EVs, of which a certain number is not able to connect to the grid. This ratio is set fixed at 20% of the total number of cars. Lastly, the ability of the energy system to absorb any excess of electricity produced depends on the SoC of the EV battery and the charge capacity per hour. Such a setup on average provides 75% of all EVs available for grid connection.

Introduction of RES led to a significant change in the energy mix for electrical sector in this scenario, despite the increase in overall consumption from 310 GWh annually in 2010 to 557 GWh in 2050. Based on H2RES calculations, the RES share went from 0% in 2010 to 14% in 2050 [Figure 9].

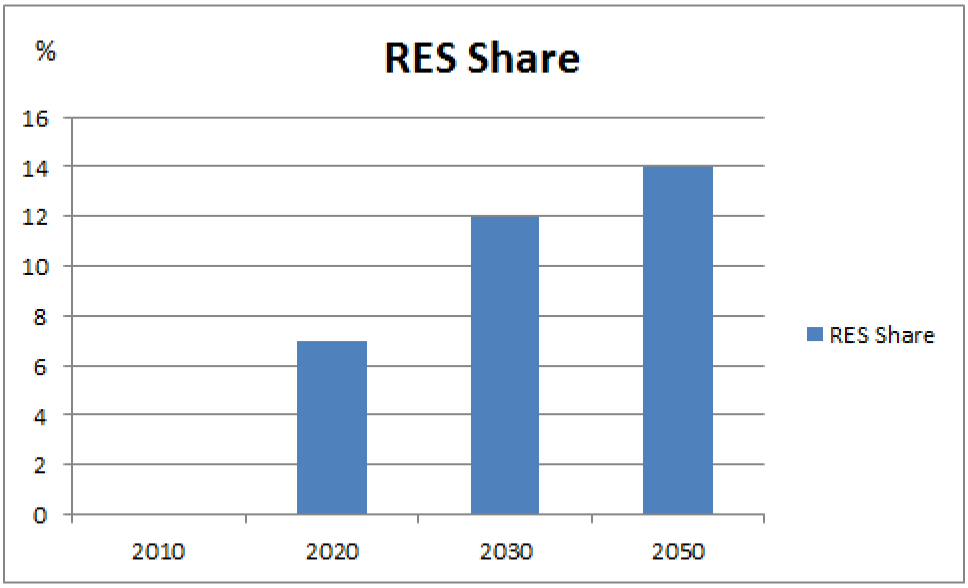

Figure 9. Share of RES in Dubrovnik scenario

All calculations were done with the fixed ratio of IL of 30% at any given time step. H2RES has the ability to calculate RES parameters such as the amount of *Intermittent Generation* (IG), *Intermittent Potential* (IP) (total available production for RES), *Intermittent Rejected* (IR), *Intermittent Taken* (IT), as well as general parameters of *Total Generation* (TG), *Non Intermittent Generation* (NG) and *Load*. Separately, due to the emphasis on storage in the effort to improve RES penetration, storage components are parameterized by variables such as storage state, amount charged and discharged, and the ability of storage to charge or discharge.

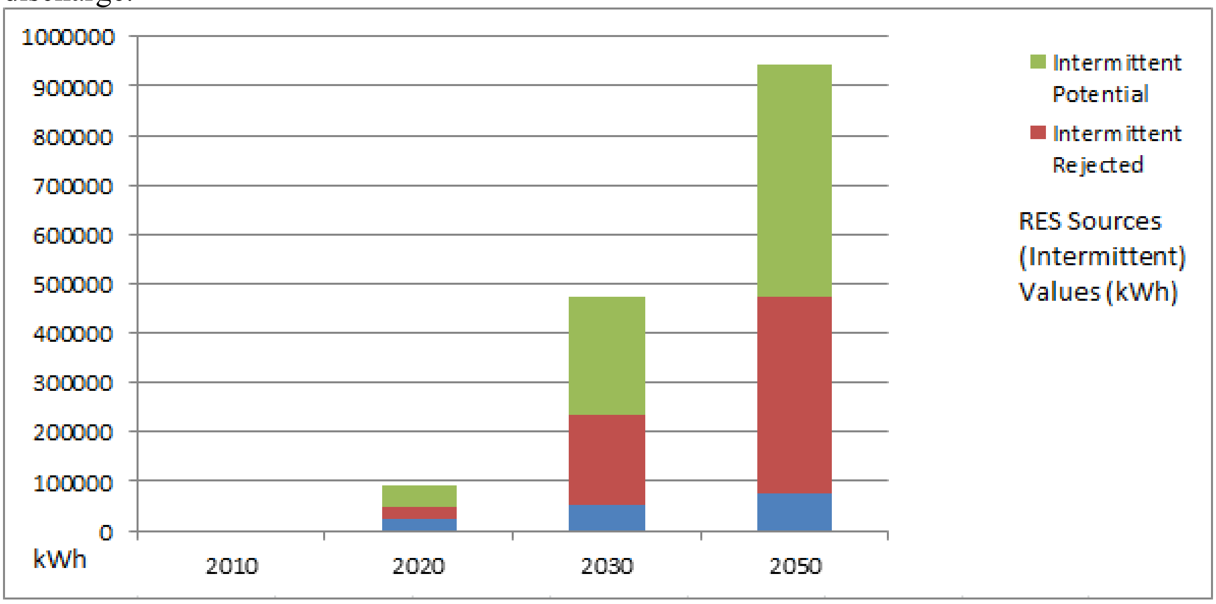

Figure 10. Breakdown of RES calculations (Potential, Taken, Rejected)

It is worth mentioning that the amount of IR increases over time [Figure 10]. This is due to the fact RES are increasing in terms of installed power and the demand is not increasing proportionally. Coupled with the fact that hydropower provides adequate coverage of current demands and even excess electricity in most years except the final period, it would be beneficial to increase the IL provided the situation enables it.

CONCLUSION

The case of Dubrovnik shows the possibility of EV integration in a long term plan. Given the current setup of the energy system, it is possible to accommodate the increase in electricity consumption derived from the electrification of transportation sector. This complies with the EU directive on diversifying the energy mix in transport sector, which is almost exclusively fossil fuel driven at the moment. Calculations show up to 14% of RES penetration is possible if the current plan of RES development is implemented. Further increase in penetration is possible if the technical requirements are met and the limit on RES generation is raised further.

Additional work is required on modelling the EV module. Generic driving cycles need to be better understood, as there will be differences in usage scenarios between EVs and classic internal combustion vehicles, at least until the performance between the two types becomes more evenly matched. More information is needed on implementation of V2G, and H2RES needs to be developed in a way that provides more options to optimize battery operations with EV. This is possible through implementation of new optimization algorithms.

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REFERENCES

[1] H. Lund, N. Duić, G. Krajačić, and M. Da Graça Carvalho, "Two energy system analysis models: A comparison of methodologies and results," *Energy*, vol. 32, no. 6, pp. 948–954, Jun. 2007.

[2] G. Krajačić, N. Duić, and M. da G. Carvalho, "H2RES, Energy planning tool for island energy systems – The case of the Island of Mljet" *International Journal of Hydrogen Energy*, vol. 34, no. 16, pp. 7015–7026, Aug. 2009.

[3] G. Krajačić, R. Martins, A. Busuttil, N. Duić, and M. da G. Carvalho, "Hydrogen as an energy vector in the islands' energy supply," *International Journal of Hydrogen Energy*, vol. 33, no. 4, pp. 1091–1103, Feb. 2008.

[4] N. Duić, M. Lerer, and M. G. Carvalho, "Increasing the supply of renewable energy sources in island energy systems," *International Journal of Sustainable Energy*, vol. 23, no. 4, pp. 177–186, Dec. 2003.

[5] N. Duić and M. da Graça Carvalho, "Increasing renewable energy sources in island energy supply: case study Porto Santo," *Renewable and Sustainable Energy Reviews*, vol. 8, no. 4, pp. 383–399, Aug. 2004.

[6] B. Antoine, K. Goran, and D. Neven, "Energy scenarios for Malta," *International Journal of Hydrogen Energy*, vol. 33, no. 16, pp. 4235–4246, Aug. 2008.

[7] M. D. Galus, M. Zima, and G. Andersson, "On integration of plug-in hybrid electric vehicles into existing power system structures," *Energy Policy*, vol. 38, no. 11, pp. 6736–6745, Nov. 2010.

[8] F. Chen, N. Duic, L. Manuel Alves, and M. da Graça Carvalho, “Renewislands—Renewable energy solutions for islands,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 8, pp. 1888–1902, Oct. 2007.

[9] A. Perujo and B. Ciuffo, “The introduction of electric vehicles in the private fleet: Potential impact on the electric supply system and on the environment. A case study for the Province of Milan, Italy,” *Energy Policy*, vol. 38, no. 8, pp. 4549–4561, Aug. 2010.

[10] F. Kley, C. Lerch, and D. Dallinger, “New business models for electric cars—A holistic approach,” *Energy Policy*, vol. 39, no. 6, pp. 3392–3403, Jun. 2011.

[11] P. Melo, R. E. Araujo, and R. de Castro, “Overview on energy management strategies for electric vehicles - Modelling, trends and research perspectives,” pp. 1–8.

[12] Croatian Bureau of Statistics, www.dzs.hr.

[13] Croatian Transmission System Operator, www.hep.hr/ops/en/aboutus/default.aspx.

[14] Registry of Renewable Projects, oie.mingorp.hr/default.aspx?id=24.

[15] Elektrojug Distribution System Operator, www.hep.hr/ods/dp/dubrovnik/.

[16] HEP Production, www.hep.hr/proizvodnja/osnovni/default.aspx.

[17] Croatian Meteorological Service, meteo.hr/index_en.php.

[18] Master Thesis, Anamarija Sare, University of Zagreb, 2012.

[19] D. Connolly, H. Lund, B. V. Mathiesen, and M. Leahy, “A review of computer tools for analysing the integration of renewable energy into various energy systems,” *Applied Energy*, vol. 87, no. 4, pp. 1059–1082, Apr. 2010.

[20] Croatian Department of Interior Affairs, www.mup.hr/10.aspx.

[21] Traffic study, City of Dubrovnik

[22] T. Pukšec, G. Krajačić, Z. Lulić, B. V. Mathiesen, and N. Duić, “Forecasting long-term energy demand of Croatian transport sector,” *Energy*, vol. 57, pp. 169–176, Aug. 2013.

[23] M. Stadler, C. Marnay, R. Sharma, G. Mendes, M. Kloess, G. Cardoso, O. Megel, and A. Siddiqui, “Modeling electric vehicle benefits connected to smart grids,” in *2011 IEEE Vehicle Power and Propulsion Conference*, 2011, pp. 1–8.

[24] H. Lund and W. Kempton, “Integration of renewable energy into the transport and electricity sectors through V2G,” *Energy Policy*, vol. 36, no. 9, pp. 3578–3587, Sep. 2008.

[25] A. Schroeder and T. Traber, “The economics of fast charging infrastructure for electric vehicles,” *Energy Policy*, vol. 43, pp. 136–144, Apr. 2012.

[26] A. S. Brouwer, T. Kuramochi, M. van den Broek, and A. Faaij, "Fulfilling the electricity demand of electric vehicles in the long term future: An evaluation of centralized and decentralized power supply systems," *Applied Energy*, vol. 107, pp. 33–51, Jul. 2013.